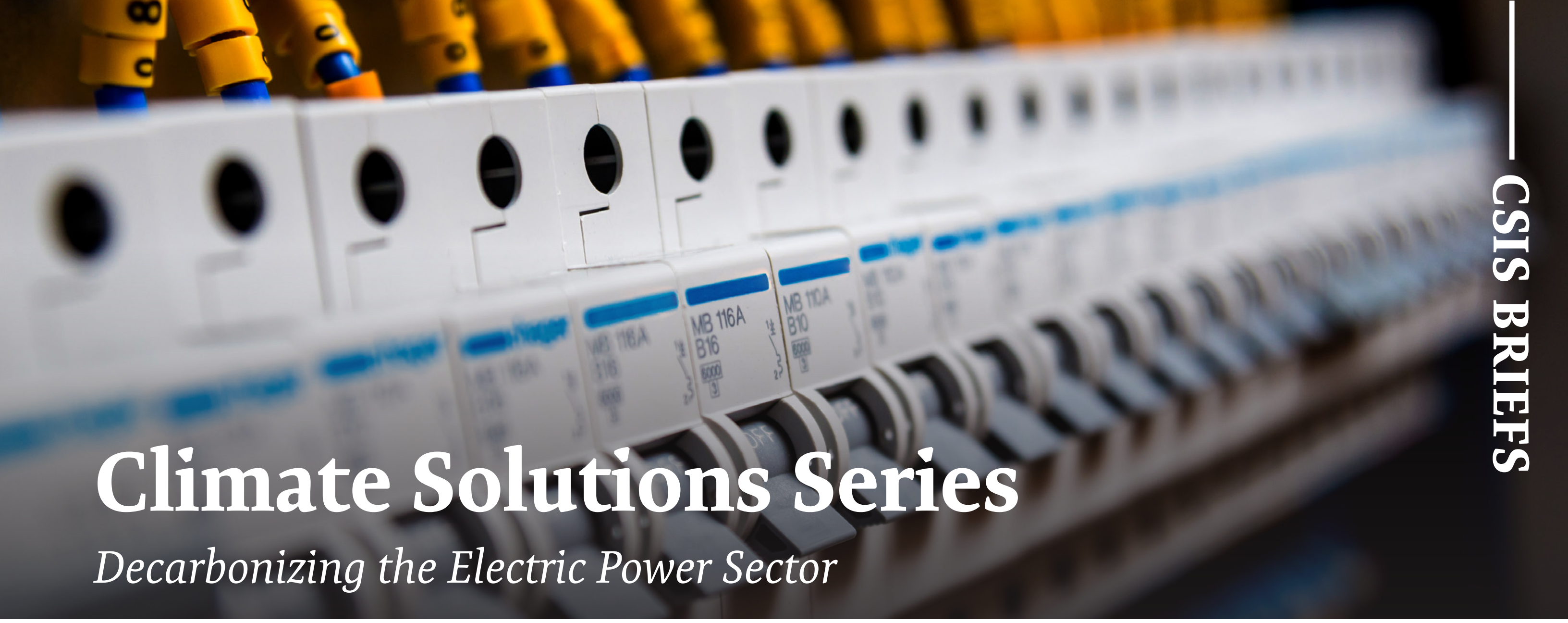

Climate Solutions Series

Decarbonizing the Electric Power Sector

By Stephen Naimoli and Sarah Ladislaw

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THE ISSUE

This brief is the second in a series on achieving net-zero global greenhouse gas emissions by 2050. The CSIS Energy Security and Climate Change Program is hosting six events that will be followed by resource briefs related to each event. For more information on the series, see our website.

THE CHALLENGE

In 2018, the power sector emitted 13.6 billion tons of carbon dioxide (CO_2) into the atmosphere, 41 percent of total global emissions.[1] To have a chance of holding global temperature rise below 1.5 degrees Celsius relative to its preindustrial level, global emissions from all economic sectors, including the power sector, must be reduced to net-zero around 2050.[2]

One of the challenges of decarbonizing the power sector is sufficiently reducing greenhouse gas (GHG) emissions while guaranteeing reliability, security, and affordability. Solar and wind power are zero-carbon technologies, but their variability could challenge grid stability if they are not properly balanced by sufficient storage and firm power. Jesse Jenkins, a Princeton professor and one of the speakers at CSIS's March 30 event on power sector decarbonization, likens the power system to a balanced diet: directly comparing the costs of variable renewable energy to those of firm power sources is like comparing the cost of a banana to the cost of a hamburger.[3] Both can be evaluated on cost alone, but doing so misses the different roles they play in a balanced electric power system.

The other major challenge is ensuring that decarbonization is equitable and accessible by both high-income countries and low-income countries. Although solar and wind have become cost competitive around the world, many low-income countries are extremely price-sensitive and will need all of the options available to high-income countries. One of the ways the high-income countries can ensure greater availability of these solutions in low-income countries is by buying down the cost of technologies and helping to create new business models to make them more accessible to price-sensitive markets.

Greater interconnection of regional power grids would be beneficial to decarbonizing electric power.[4] This would create more opportunities to add solar and wind generation where the best wind and solar resources are available and to send the power they generate to other areas. However, this would require a significant buildout of transmission infrastructure, something that is extremely difficult due to high capital costs, disputes over who will pay for the lines and who will benefit financially, and, frequently, opposition from communities through which the wires would run.[5]

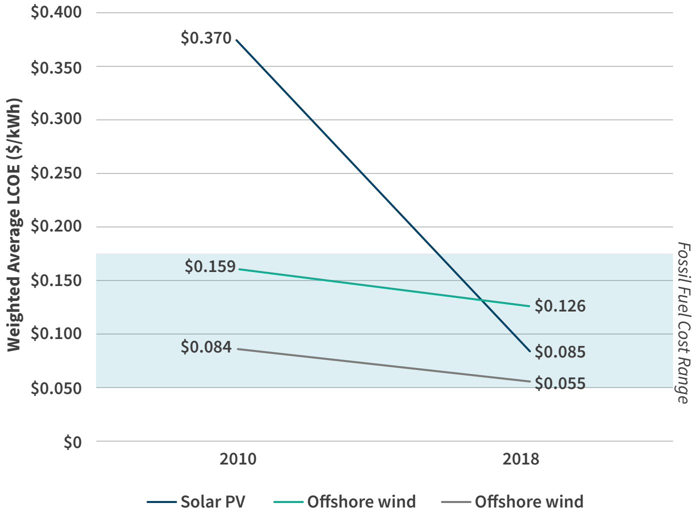
Finally, decarbonization is likely to hinge on increased electrification of other sectors. Therefore, the electric power sector may need to grow capacity or increase efficiency as it decarbonizes. This will occur while the sector also changes in other ways, including the development of increasingly complex networks of supply and demand, new demands for bidirectional flow of power, new business models for power generation and grid infrastructure development, and increasing digitization of power technology. These will all present new challenges for the electric power sector to overcome.

GETTING FROM HERE TO THERE

TECHNOLOGY

Renewables like solar and wind power are perhaps the most widely recognized zero-carbon technologies and are likely to be central to a decarbonized power system. As of 2019, there were about 586 gigawatts (GW) of solar power installed around the world (about 8 percent of total installed electricity generation capacity) and about 623 GW of wind power (about 9 percent of total generation capacity).[6] Currently, 3 percent of global electricity generation comes from solar and 6 percent comes from wind.[7] Solar and wind costs have fallen dramatically over the past decade. The cost of solar photovoltaics declined from $0.371 per kilowatt-hour (kWh) in 2010 to $0.085 per kWh in 2018 and continues to fall.[8] Onshore wind declined from $0.085 per kWh to $0.056 over the same time period, and offshore wind declined from $0.159 to $0.127. Solar and wind power benefit from having zero fuel costs. However, they are variable, as they will only generate electricity when the sun is shining or the wind is blowing. Therefore, firm resources and grid flexibility will be necessary to complement these methods of power generation.

Figure 1: Selected Renewable Energy Technology Cost Trends, 2010–2018



Source: International Renewable Energy Agency, Renewable Energy Power Generation Costs in 2018 (Abu Dhabi: IRENA, 2019), https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf.

The other class of renewable energy technologies is made up of firm resources—ones that can depend on some type of "fuel" (although not necessarily one that has an associated cost) and are dispatchable. These include geothermal, hydropower, and bioenergy. As of 2019, there were about 14 GW of geothermal, 1,310 GW of hydropower, and about 124 GW of bioenergy installed around the world.[9] Solar and wind are much cheaper than geothermal or bioenergy, and their construction tends to have fewer environmental and resource availability impacts than hydropower development. However, these firm resources are dispatchable and can thus provide power that can be used when variable renewable resources such as wind and solar experience major extended supply shortfalls relative to their diurnal and seasonal norms. Biomass power, when combined with carbon capture and sequestration, can play a particularly important role in supporting progress toward a net-zero electricity system. Generation using sustainably sourced biomass together with carbon capture technology (discussed below) can provide power with net negative emissions, which may be critical to offsetting remaining generation that has very small positive emissions.

> *Renewables like solar and wind power are perhaps the most widely recognized zero-carbon technologies and are likely to be central to a decarbonized power system.*

Energy storage is also likely to play a significant role in decarbonizing the electric power sector. Lithium-ion batteries, used both in electric vehicles and in stationary storage applications, have seen dramatic cost declines in recent years, falling from $1,100 per kWh in 2010 to $156 per kWh in 2019.[10] Correspondingly, battery deployments are growing dramatically—energy analysis firm Wood Mackenzie predicts the market will grow from 12 gigawatt-hours (GWh) in 2018 to 158 GWh in 2024.[11] Other battery chemistries, such as sodium sulfur or zinc-air batteries, are in development or in use, but lithium-ion currently holds the economic advantage. The most prevalent technology for energy storage, however, is pumped hydro storage, which uses electricity to pump water from a lower reservoir to a higher one (storing the energy) and generates electricity by running the water downhill through turbines. Of currently installed energy storage, 94 percent is pumped hydro.[12]

It is worth noting that with current technology, lithium-ion batteries can economically store energy for about four hours at a time.[13] Although pumped hydro can store energy for long periods of time, high capital costs and concerns about environmental impacts make building new facilities very difficult. Therefore, researchers are developing new long-duration storage technologies, including vanadium redox flow batteries or mechanical storage techniques that utilize a crane lifting and dropping blocks to store and generate electricity.

Another long-duration storage option may be electrolytic hydrogen, which is produced by splitting water into hydrogen and oxygen via an electrolyzer. The electrolyzer can use excess renewable energy to separate the hydrogen, then the hydrogen can remain unused for long periods of time until it is needed to power a turbine via a fuel cell to create electricity. One of the advantages of hydrogen is that current coal- or gas-fired power plants can be converted to run on hydrogen. High-profile projects to demonstrate this conversion potential are emerging, including in Utah and the Netherlands.[14] Large-scale use of electrolysis will require a significant reduction in cost, as electrolytic hydrogen is currently uncompetitive with hydrogen produced from fossil fuels.[15]

The amount of "optimal" storage in a future decarbonized grid will vary depending on the cost of storage and clean generation resources in a given area, how much extra generation capacity is built, the extent of grid interconnection, and the flexibility of demand, among other factors. This makes answering questions about the ultimate role of storage on the grid quite difficult. Rather, its role will be revealed over time.

Non-renewable firm power with either no or very low emissions can also play an important role in an efficient decarbonized power system.[16] Currently the most promising technologies to fill this role are nuclear power and fossil fuels with carbon capture, use, and sequestration (CCUS). Interest in nuclear power has waxed and waned over the years, largely thanks to high-profile disasters in the 1970s, 1980s, and more recently in 2011 and the high capital cost of nuclear plants. Countries such as China, Russia, and South Korea are building new large-scale nuclear power plants, and India has pledged to build more as well.[17] However, the next generation of nuclear power is likely to come from small, modular reactors (SMR). This category of technologies is beginning to enter the demonstration phase of development and is not likely to be deployed at commercial scale in the next few years. If proven viable and safe, it could be a key part of a decarbonized electric power sector because it would be dispatchable and flexible, and its modular size would allow for minimizing capital costs and potentially avoiding siting issues.

Carbon capture can refer to a number of technologies but most often refers to post-combustion scrubbers that are added to the smokestack of a carbon-emitting source. In the power sector, this would typically mean coal, gas, or oil-fired generators. The "use and sequestration" part of CCUS refers to either using or storing the captured carbon in other ways, such as using it to make carbon-intensive products or permanently storing it in geologic formations. Unless CO_2 is stored or used directly where it is captured, it requires a buildout of new pipelines to transport it. The Global CCS Institute estimates that to be on track to halve global emissions by 2050, we would need 100 times the 6,500 km of CO_2 pipeline capacity that exists today.[18] Carbon capture technology cannot capture 100 percent of emissions, so either fossil fuels with CCUS would need to be a purely transitional strategy to a net-zero future or additional carbon-negative efforts such as bioenergy with carbon capture would be necessary to offset the remaining emissions.

It is generally accepted by climate and energy analysts that some level of CCUS will be necessary to decarbonize the world by 2050 because it will allow for decreased capital costs and the ability to overcome the barriers to overhaul the energy system in 30 years.[19] CCUS faces some opposition due to concerns about potential leakage of stored CO_2 or investments going to maintaining fossil fuel use when they could go to deploying renewables.[20] However, these points are debated in the academic community and have not yet been settled. As of 2019, 19 carbon capture facilities around the world collectively captured approximately 25 million tons of CO_2.[21] The International Energy Agency's Sustainable Development Scenario, consistent with a 2-degree scenario by 2050, predicts that the world will need to capture 350 million tons of CO_2 per year by 2030.[22] The world will need to scale up CCUS significantly if this is to happen.

Another notable technology in development does not use typical post-combustion carbon capture equipment but does promise to remove and sequester CO_2 from natural gas. A Texas company called NET Power has built and operated a 30 MW pilot plant using the Allam cycle, which burns natural gas with oxygen and uses the resultant CO_2 rather than steam to power the turbine. The CO_2, which is already a pure stream at high pressure, is either recycled within the system or sent to others via pipeline for use or sequestration.[23] This technology, if it proves scalable, would not provide the option to retrofit currently existing natural gas-fired plants but would provide an option to use natural gas to generate electricity more efficiently than a traditional plant with carbon capture, potentially at lower costs and without CO_2 emissions.[24]

Grid flexibility will be critical to a low-cost, decarbonized electric power sector. Grid flexibility refers to the ability of supply or demand, or both, to adjust to balance the system to achieve a desired outcome, such as keeping prices low or minimizing GHG emissions. Demand flexibility can be facilitated either by technology (e.g., a smart thermostat that can ramp up and down based on total supply and demand) or through behavior change (e.g., pricing programs that incentivize customers to use less electricity during peak demand times). Supply flexibility is enabled by resources that can ramp up and down quickly, such as natural gas peaker plants or grid-connected batteries. Both demand and supply flexibility are likely to be necessary to help balance a decarbonized grid.

Grid flexibility can offer the chance to avoid new investments in transmission infrastructure. Utilities can choose to invest in “non-wires alternatives,” such as batteries deployed in the transmission or distribution system, distributed generation, energy efficiency upgrades, or demand response efforts. These projects can help avoid new capital costs and drawn-out fights over siting new wires. However, increasing deployment of alternatives to transmission and distribution lines may come into conflict with the development of regional transmission infrastructure. Ultimately, efficient decarbonization will require a mix of local zero-carbon energy and long-distance transmission lines to bring zero-carbon power from resource-rich areas. Decisionmakers must determine how to balance the two to optimize their decarbonization plans.

POLICY

Policies to push deployment were crucial in the early days of renewable energy. Although modern solar power had been in development in the United States since the mid-twentieth century, the rise of solar deployment began with the United States in the 1970s and Germany in the early 2000s. Germany’s feed-in tariffs and various federal and state-level efforts in the United States provided certainty and created demand for solar producers, allowing them to push the technology down the cost curve through experience and scale. Modern wind power has seen support from similar efforts. Now that prices have fallen, economics have begun to take over and become a major driver of deployment. In some cases, companies are getting out ahead of 100 percent clean energy goals, including U.S. utilities such as Xcel Energy, Idaho Power, and Duke Energy. In many places, the dominant policy challenge in the short term is integrating new renewable energy onto the grid.

Still, in the long term, policies will likely be needed to drive deployment, as not all actors will be willing to shift to clean energy on their own and not in the time frame necessary. Many of these policies have been discussed in the previous brief in this series.[25] However, there are some nuances that warrant some further exploration in this brief. One of the most direct policies to push deployment that was discussed in the previous brief in this series is the sales mandate. Sales mandates are popular in the decarbonization discussion—government can demand that utilities and retailers ensure a certain percentage of electricity sold comes from a particular source. Historically, this has taken the form of a Renewable Portfolio Standard (RPS), where a percentage of sales must be from certain renewable energy sources prescribed in law. In recent years, however, a somewhat new idea has re-emerged: the Clean Electricity Standard (CES). The CES differs from an RPS in that it can allow generation not only from renewable energy but also other zero-carbon sources such as nuclear, fossil fuels with carbon capture, hydrogen made from electrolysis, or fossil fuels with carbon capture. To the proponents of the CES, one of its advantages is that it allows for more flexibility in meeting the same goal of decarbonizing the electricity system. Having a larger suite of solutions is beneficial to decarbonization because it leaves room for innovative new technologies and ensures that the least-cost options are available to decisionmakers.

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Decarbonization of the power sector is a goal in and of itself. However, decarbonizing the power sector will also help decarbonize other sectors, to the extent that it will be possible to electrify those sectors. Given the lack of identifiable, zero-carbon alternatives in other sectors, electrification is expected to play a major part in decarbonization, especially in areas such as transportation and buildings.[26] However, electrification will only help deep decarbonization efforts if the electric power sector decarbonizes as well. Therefore, there is merit in taking more systems-level approaches to allow for parallel decarbonization of the power sector and other sectors. The European Union considers this approach "sector coupling," and recent research indicates it could contribute 60 percent of the European Union's intended emissions reductions by 2050.[27]

At present, most analysts believe that we do not have every single tool we need to get to net-zero emissions. However, we do have many of the tools we need. It can be useful to think of decarbonization in chapters. Variable renewable energy is available and relatively cheap now. Short-duration energy storage is quickly becoming economic. Those solutions are scalable now and can make a significant contribution to decarbonization in the short term. Some firm, zero-carbon power sources such as geothermal and hydropower are available now but face economic or social barriers to deployment. Governments and the private sector can determine how to address these barriers in the next 10 years. Promising new technologies, such as advanced nuclear, CCUS, and long-duration storage, are being developed and tested now and can reasonably be expected to be scalable by 2030 or 2040. There is every reason to deploy technologies as they become available while also planning for future solutions that will join the suite of decarbonization options.

Given the lack of identifiable, zero-carbon alternatives in other sectors, electrification is expected to play a major part in decarbonization, especially in areas such as transportation and buildings.

THE ROLE OF PRIVATE SECTOR ENGAGEMENT

In some countries such as the United States, the private sector is the dominant player in the power sector. Of the approximately 3,000 utilities in the United States in 2017, only about 200 were privately-owned, but those privately-owned utilities served 72 percent of the country's customers that year.[28] The private sector has also gained a larger role in many other parts of the world as their countries have opened up their power sectors to private competition.[29] In Vietnam, for example, the government has been gradually restructuring the historically state-owned power sector to allow for competition in generation, wholesale power, and retail power.

In this context, decarbonizing the electric power sector will require significant efforts by the private sector. In addition, private sector developers are heavily invested in building power generation around the world, and governments can influence their decisions to build different generation technologies. In the power sector decarbonization event with CSIS, AES Chief Technology Innovation Officer Chris Shelton noted that renewable power generation was a growing and competitive business for the company.[30] He also emphasized the role of ramping down existing fossil fuel-fired generation to facilitate renewable energy integration and how policy can play a role. In Chile, he told us, developers are building new wind and solar generation, and existing oil-fired plant owners are ramping down their capacity factors but keeping the plants around for backup. Chris pointed out that governments can incentivize this behavior to replace carbon-intensive generation with zero-carbon generation while allaying concerns of adding renewables too quickly or fostering early retirements. He also emphasized that governments should create new tax incentives for private sector developers that identify new uses for captured CO_2. Also during the event, Sue Tierney, a senior adviser at Analysis Group, told us she believes there is plenty of appetite among utilities for decarbonization goals that identify targets between now and 2050 rather than a single goal set in 2050.

The private sector is also a major purchaser of power. In 2017, the commercial and industrial sectors used 64 percent of the world's electricity.[31] These companies are increasingly buying clean energy to power their operations—in 2019, 100 corporations signed contracts with renewable energy producers, for 19.5 GW of power.[32] Companies are not only signing power purchase agreements, either. The Renewable Energy Buyers Alliance, a group of large-scale energy consumers, including companies and non-profit organizations, has committed to "catalyze 60 GW of new renewable energy projects by 2025" through purchasing power, educating other energy consumers, and advocating for policy and market changes to make it easier for retail customers to buy renewable energy.[33]

CONCLUSION

Decarbonization of the power sector is already underway with the tools currently available. The electric power sector is often regarded as the "easiest" sector to decarbonize, compared with highly diffuse sectors such as transportation, because of the large number of solutions available and the relative ease of transitioning a relatively limited number of generally centralized assets. There has been significant progress in decarbonizing electricity in recent years, exemplified by a 33 percent (800 million ton) decline in U.S. electricity system emissions by 2019 from their peak in 2007 despite a nearly identical generation level. However, future progress will pose significant challenges, especially as net emissions approach zero. The electric power sector is also changing in other ways, including increasing complexity, digitization, and the need for new business models. Deep decarbonization in the sector will require further deployment of current technologies, such as solar power, wind power, and lithium-ion batteries, alongside new solutions that are not yet commercially available, including advanced nuclear and widespread CCUS. Given the global nature of climate change, international cooperation will be needed to fully confront the problem, and this will have to include efforts by high-income countries to buy down the cost of technologies to make them more viable in markets with less access to capital. Efficient decarbonization of the power sector can occur alongside decarbonization of other sectors as long as governments are able to think holistically about decarbonization and maximize the benefits of electrification. Further briefs in this series will explore other sectors and the role that electrification can play in each segment of the global economy.

Stephen Naimoli *is a research associate with the Energy Security and Climate Change Program at the Center for Strategic and International Studies (CSIS) in Washington, D.C.* ***Sarah Ladislaw*** *is senior vice president and director of the CSIS Energy Security and Climate Change Program.*

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